Process Analytical Technology: How much oxygen is inside?

Over the last decades, advances in Process Analytical Technology (PAT) have significantly improved our ability to monitor the feed stock, reactants and product compositions of chemical processes – online or inline. This qualitative and quantitative process information help us to run the processes stable and at its optimum, and it opens the gate for further process optimization of the production plant.

For many chemical and petro-chemical processes, the online monitoring of the oxygen concentration before/during/after the reaction and/or exhaust streams is of high relevance due to

1. Optimized plant operation (yield, product quality) and/or
2. Plant safety (protection of explosive mixture).

You are an expert for PAT in the company. The plant manager of the ethylene oxide production is approaching you and your team with the following request.

Ethylene oxide is produced in a continuous process by direct oxidation of ethylene by oxygen/air and a silver-based catalyst:

\[ 2\text{CH}_2\text{=CH}_2 + \text{O}_2 \xrightarrow{\text{Ag}} 2(\text{CH}_2\text{CH}_2)\text{O} \]

The concentration of oxygen is one crucial parameter to prevent further oxidation of ethylene oxide to CO\(_2\) and H\(_2\)O. Thus, the oxygen concentration before and after the reactor has to be carefully monitored and controlled to ensure that the maximum oxygen concentration does not exceed the critical limit. Some further facts/needs:

- Typical concentration of oxygen: 6 – 8 Vol. %
- Temperature range: 200 – 280 °C
- Pressure range: 10 – 20 bar
- High reliability of the analytical method / instrument
- Gas is consisting different components (organic compounds)
- Fluctuations of gas pressure might be possible
- Installation of the instrument in explosive protected area (ATEX zone 2)
Questions

1. **There are various analytical methods for the detection of oxygen possible/available**
   What kind of analytical methods for online/inline monitoring of oxygen concentration are suitable at all?

2. **Advantages/Disadvantages**
   Please discuss the advantages/disadvantages of the individual analytical methods in combination with the economic impact of each measurement (cross sensitivities, response time, calibration, investment, maintenance costs).

3. **Inline/online & atline**
   What are differences between inline, online, atline and offline analyses?

4. **Link of the instrument to the process**
   Which aspects need to be considered to connect an instrument to a production process?

5. **Explosion protection (ATEX = atmosphere explosive)**
   An installation directly inside the petro-chemical production plant requires special conditions. The atmosphere inside the plant might classify as "explosion protected and preventive area". Instruments known from the research lab cannot be installed directly in a chemical plant. Consider safety precautions that have to be addressed to place the analytical instrument inside the plant.

6. **Explosion protection (Classification of sensors/analyzers)**
   A sensor/analyzer is marked as follow:
   CE 0035 II 2G Ex ia IIC T4
   What kind of information can be derived from these labeling?

7. **Your choice**
   Please make a proposal for an online measurement to the plant manager and justify your selection to the management team of the production plant!

**Literature:**